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Study of bremsstrahlung in α decay in a realistic potential

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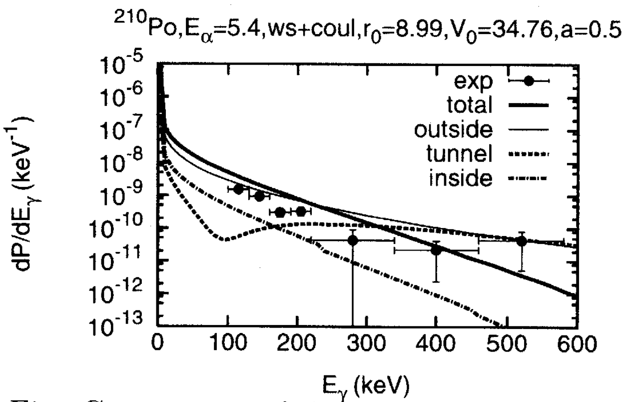
The α decay is one of the typical quantum tunneling phenomena. When one considers bremsstrahlung in α decay, there arises a question whether there exists a bremsstrahlung during the tunneling process. To clarify this problem, Kasagi et al. have measured the spectrum of the bremsstrahlung γ ray in the α decay from ^{210}Po, and have shown that the emission probability of high energy γ ray is systematically smaller than the prediction of the classical electromagnetic theory [1]. They speculated that this reduction has been caused by the interference between the radiations in the tunneling and in the classically allowed regions. Theoretically, Papenbrock and Bertsch have performed quantum mechanical calculations. They well reproduced the experimental data of Kasagi et al., but have concluded that the contribution from the tunneling region is small. In this way, there remain debates on the origin of the bremsstrahlung in α decay, especially on the radiation during the tunneling process.

In master thesis, I studied the bremsstrahlung spectrum in a simple model, where the potential between the α particle and the daughter nucleus is represented by a square well potential at short distances and by $\frac{1}{r}$ Coulomb potential at large distances, r being the distance of the α particle from the daughter nucleus. In order to identify the bremsstrahlung from the tunneling region, I divided the whole matrix element of the bremsstrahlung into the contributions from four different spatial regions. We call them the wall position, the tunnel region, the mixed region and the classical region. The mixed region is the region, which is classically allowed in the initial state, i.e. before the emission of γ ray, but becomes classically forbidden in the final state after emitting the γ ray. I have thus shown that the radiations from all the spatial regions significantly contribute, and their interference plays the crucial role in determining the final spectrum of bremsstrahlung. Moreover, I discussed the connection between the bremsstrahlung in quantum mechanics and in classical electrodynamics by representing the initial and final state wave functions in the WKB approximations. These results have been published [2].

However, it is not obvious whether the conclusions derived in the simple model, i.e. the square well $+\frac{1}{r}$ Coulomb potential model, hold in the actual bremsstrahlung in α decay. One of the main aims of my thesis is to answer this question by calculating the bremsstrahlung spectrum in α decay by using a realistic model, where the nuclear potential is represented by the Woods-Saxon potential and the Coulomb potential by that of a uniformly charged sphere.

[1] J. Kasagi et al. Phys. Rev. Lett. **79**,371(1997)
[2] N. Takigawa, Y. Nozawa, K. Hagino, A. Ono, and D. M. Brink, Phys. Rev. C**59**,R593 (1999)



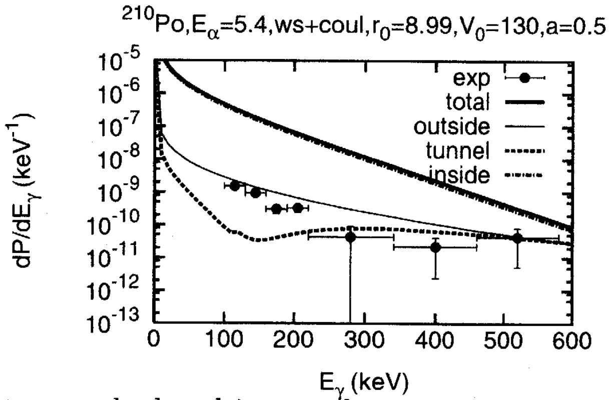


Fig. Comparison of the bremsstrahlung spectrum calculated in a realistic potential with two different sets of parameters with the experimental data. The left figure shows the results of a shallow potential, while the right figure those of a deep potential.

The figures compare the bremsstrahlung spectrum calculated by two different potentials with the experimental data for the α deacy of ^{210}Po. In both calculations, the range and the surface diffuseness parameters of the Woods-Saxon potential, r_0 and a, have been fixed to be $r_0 = 8.99fm$ and $a = 0.5fm$, respectively. The depth parameter V_0 and the preformation factor P have been determined to reproduce the Q-value and the lifetime of the α decay by assuming the number of nodes in the radial wave function of the relative motion between the α particle and the daughter nucleus to be $n = 1$ and $n = 5$ for the left and the right figures, respectively. The former and the latter thus correspond to a shallow and a slightly deeper potentials, respectively.

The calculated spectrum(the thick solid line) well agrees with the experimental data when one uses the shallow potential (left figure). One also observes that the final spectrum is given by the interference between the radiation from the classical and the tunneling regions. These conclusions match with those obtained by using a simple square well+ $\frac{1}{r}$ model. On the other hand, the bremsmstrahlung becomes too strong compared with the experimental data when one uses the deep potential (right figure). As the figure shows, this reflects too strong radiation from the inside region. These results seem to indicate that the bremsstrahlung chooses a shallow potential than a deep potential and resolves the longstanding ambiguity of the potential between the α particle and the daughter nucleus concerning the depth. This contradicts, however, to the fact that even larger number of node, i.e. n=11, is predicted by the consideration of the number of quanta in comparing the shell model and the cluster model wave functions. The development of a new theory to resolve this puzzling situation is strongly awaited.

In the thesis, I have also shown that the bremsstrahlung spectrum is sensitive to the surface diffuseness parameter. I have also shown that the theoretical calculations in both realistic model and a simple square well potential model do not agree with the experimental data by an Italian group for the bremsstrahlung in the α decay from ^{214}Po and ^{226}Ra. Comparing the bremsstrahlung in the α decay of ^{210,212,214}Po, I have also shown that the bremsstrahlung from the tunneling region manifests itself more clearly in the α decay with a smaller Q value.